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U. S. ARMY TEST AND EVALUATION COMMAND DEVELOPMENT TEST II (EP) - COMMON TEST OPERATIONS PROCEDURES "RESISTANCE OF ARMORED VEHICLES TO SEVERE SHOCK"

Army Test and Evaluation Command
Aberdeen Proving Ground, Maryland

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Provides a method for evaluating the resistance of armored vehicle fire control and other components to shock from KE projectile impacts and blast and fragmentation from exploding HE projectiles. Describes acceleration, strain, and deflection instrumentation. Tests include high energy impacts on bare armor and "sacrificial" armor, graduated energy impacts with proof projectiles, and static detonations of HE projectiles for blast and fragmentation effects. Describes shock data analysis procedures.

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U. S. ARMY TEST AND EVALUATION COMMAND
DEVELOPMENT TEST II (EP) - COMMON TEST OPERATIONS PROCEDURES

AMSTE-RP-702-101
*Test Operations Procedure 2-2-620 13 November 1975

RESISTANCE OF ARMORED VEHICLES TO SEVERE SHOCK

SECTION I
GENERAL

1. Purpose and Scope. This document provides procedures for evaluating the ability of armored vehicle components, particularly fire control equipment, to endure the shock from kinetic energy projectiles impacting on the vehicle, and the blast and fragmentation from exploding HE projectiles.

2. Background. Armored vehicles are designed not only to prevent various types of attacking projectiles from perforating the armor, but also to possess subsystems and components which are rugged enough and mounted in such a way that they will continue to function properly after the tank is struck by a projectile that imposes severe shock but does not enter the vehicle. To assure that these subsystems and components are in fact able to withstand any nonperforating attack, resistance-to-shock tests are conducted. The engineer has a choice of several different methods of imposing severe shock to an armored vehicle, all of which are discussed herein together with advantages and limitations.

*This TOP supersedes MTP 2-2-620, 10 April 1970.

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Since this subtest of combat vehicles is expensive and may destroy the test item, the number of items subjected to the test is very small (usually one). It is therefore required that the test(s) provide the maximum amount of data. The placement of accelerometers on the components of interest inside the vehicle will provide basic shock data which can then be simulated in the laboratory on an individual basis to support reliability and vulnerability subtests

The most critical interior components that must be designed with adequate shock resistance are those associated with the aiming of the main weapon. If a tank is in a battle and has received a nonperforating hit, it should be able to return fire effectively. The critical components include range finders, telescopes, periscopes, ballistic computers, turret control systems, loading devices, stabilization devices, the primary and secondary weapon systems, and the latest complex and sophisticated weapon systems.

Other shock-related topics such as the measurement of shock on anthropomorphic dummies that simulate crew members, and the shock effect of land mines, are covered in TOP 2-2-617.

3. Equipment and Facilities. Equipment and instrumentation are covered in section II.

SECTION II
TEST PROCEDURES

4. Installation of Instrumentation.

4.1 Acceleration Instrumentation. Accelerometers are the principal sensors, sometimes the only sensors, used in shock tests of armored vehicles. An accelerometer is a pickup or transducer that generates, by means of a piezoelectric crystal (usually quartz), a voltage that is proportional to acceleration. The crystal develops the voltage, which is recorded on magnetic tape as g level versus time, when a small weight deforms the crystal. A high energy impact will generate a high-level acceleration initially that will dampen out through a series of decreasing positive and negative oscillations.

Accelerometers are available in many ranges of frequency responses, such as 5 to 15,000, 1.5 to 10,000, and 3 to 4,000 Hertz, and in a wide range of g levels. The selection of accelerometers will depend upon the g levels and frequencies expected to be encountered at each mounting position. Typical estimates of g levels for a projectile striking a gun shield are: 150 g for turret roof, 1000 g for traverse gearbox, and 10,000 g for the gun shield. Some accelerometers are mounted to critical components of concern to designers who require information on the accelerations that components must withstand if they are mounted to specific shock mounts. Such components include range finders, the missile system tracker-transmitter shown in figure 1, computers, turret controls,

radios, and telescopes. Other accelerometers are mounted to the turret walls to obtain baseline data to compare vehicles and impact locations, and to determine the environment that the combination of shock mount and component must withstand. When data are required on shock imparted to the crew, accelerometers are mounted to seats and platforms. Since accelerometers, for all practical purposes, are unidirectional, many positions would be monitored with three accelerometers: vertical, longitudinal, and transverse. Some accelerometers, called triaxial, have the three axis responses built into one unit.

Figure 1. Accelerometers Mounted on a Shillelagh Missile System Tracker Transmitter.

4.2 Strain Instrumentation. The specific types and locations of strain instruments are selected in accordance with the following:

a. Sections of anticipated high stress, such as mounting brackets, ballistic linkages, etc., may be instrumented with strain gages for strain-time information in accordance with TOP/MTP 3-2-808.

b. Proper placement of strain gages is difficult to anticipate. The test director may require initial test results and data on early component failures before determining the specific application of this type of instrumentation.

c. The resulting data are useful, and essential, if component strengthening is the most practical means of overcoming shock failures.

4.3 **Deflection Instrumentation.** The specific types and locations of deflection instruments are selected in consideration of the following:

a. Deflection measurements are useful in predicting clearance requirements between flexible components and nearby fixed assemblies.

b. Clearance for crew members must be checked to avoid the possibility of serious injury occurrences (such as the telescope eyepiece assembly striking the gunner's eye).

c. Low frequency deflection measurements may be obtained with strain-gaged bend bars (fig. 2), De Forest scratch gages, differential transformers, linear potentiometers, or lead cones. (Lead cones may be used for both high and low frequency measurements.)

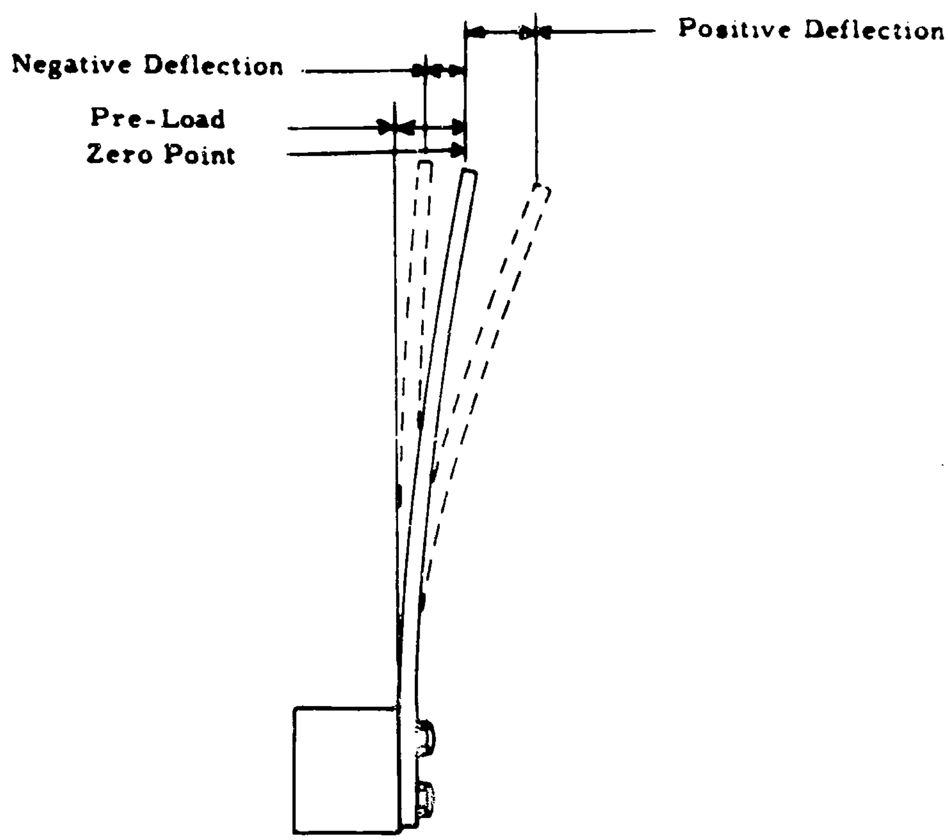


Figure 2. Bend Bar Measuring Deflection (Side View).

d. For high frequency response, noncontacting displacement measurements, the photoelectric or magnetic flux method is recommended.

Deflection instruments are defined as follows:

a. Linear potentiometer - a resistive element and contactor arranged in a straight line (fig. 3).

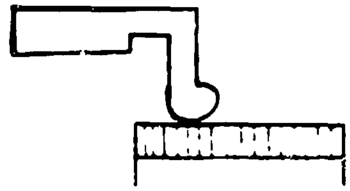


Figure 3. Linear Potentiometer.

b. Lead cone - made of lead, machined into a conical shape and used to obtain maximum displacements. It must be positioned so that its point just contacts the surface expected to move. The cone is crushed to the extent of the surface's maximum displacement, and the measurement of the new height of the cone determines the displacement.

c. Photoelectric devices (for noncontacting displacement measurements) - There are several methods of determining displacement by photoelectric means as follows:

(1) A Fotonic sensor - a device that uses fiber optics to direct a beam of light on a surface, and to receive the reflected light. Movement of the surface is correlated with the intensity of the reflected light.

(2) A stationary photocell that views a light source placed on the surface whose motion is being measured. Movement of the surface is correlated with the position of the light impinging on the photocell. With a circular photocell the image can be determined in terms of the X, Y coordinates. If the photocell is linear, the image position would be expressed only in terms of the X coordinate.

(3) A stationary vidicon tube that can view the movement of the target provided the target is of high contrast.

d. Magnetic flux - a pickup device that transmits a magnetic flux wave which is reflected by any ferrous material (also aluminum in most cases). The signal conditioning equipment that is connected to the pickup device determines the distance to the target by analysis of the wave reflected back to the pickup device.

4.4 Striking Velocity Instrumentation. Solenoid coils ordinarily are used for measuring projectile velocity, but other means are available as indicated in TOP/MTP 4-2-805.

5. High Energy Impacts on Bare Armor.

5.1 Objectives.

a. To determine the ability of the test vehicle and its components to withstand nonperforating impacts from armor-piercing projectiles.

b. To obtain shock data suitable for use by engineers designing vehicle components.

5.2 Standards. The turret must be able to withstand two impacts from armor-piercing projectiles (usually 90-mm or 105-mm) striking armor areas at approximately 300 fps below the ballistic limits. (NOTE: The projectile selected will be the same as that specified in the ROC or DP.) Projectiles should impact within a 60° frontal arc (fig. 4), one on each side of the turret. The performances of components and subsystems must not be degraded, as a result of a projectile impact, to the point that they can appreciably affect accomplishment of mission. Degradation criteria for each subsystem will be extracted, where possible, from mission failure definitions that contain degraded mode limits. Degradation is usually expressed as a numerical factor. For example, increasing a handle force from 5 pounds to 10 pounds represents degradation by a factor of two.

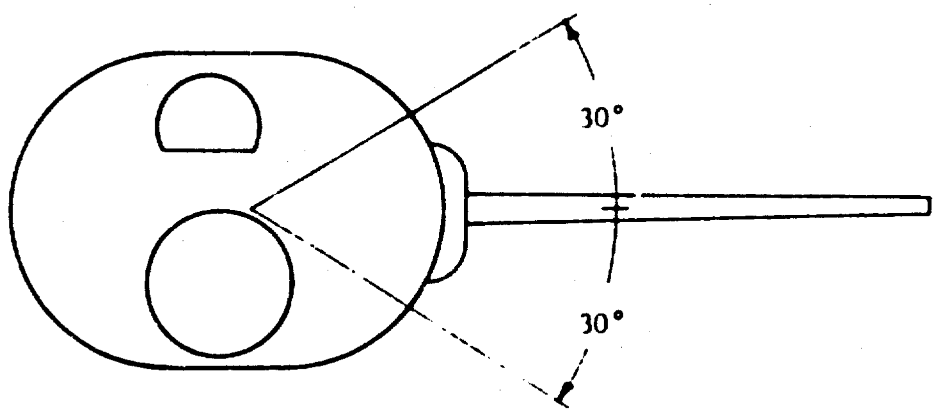


Figure 4. Frontal Cone of Turret to be Subjected to Attack.

5.3 Method. All components of interest in the vehicle are checked for integrity of mount and their performance ascertained before the shock impact. This may, as appropriate, include:

a. Boresight alignment (TOP/MTP 3-2-604).

b. Sight parallelogram error and backlash (TOP/MTP 3-2-701).

c. Range finder collimation (TOP/MTP 3-2-814).

d. Ballistic computer accuracies (TOP/MTP 3-2-700).

e. Traverse and elevation responses, handwheel torques, and brief samplings of tracking and laying performance as described in TOP/MTP 3-2-603.

Appropriate instrumentation, described in paragraph 4, is installed inside of the turret and checked for response.

The preferred points of impact are two-thirds of the way up the turret on one side and one-third up the turret on the other, with projectiles impacting from 10° off the centerline to the right in one case and 10° to the left in the other. (If 10° is not feasible, any angle up to 30° may be used.) For each intended point of impact the ballistic limit is estimated for the particular thickness and obliquity, using ballistic information from a data bank. Projectiles are fired to impact at striking velocities about 300 fps below the estimated ballistic limit. Projectile velocities are controlled by adjusting propellant weights. Following each impact, all interior components of the turret are examined for damage, and a check is made of all fire control components and components listed in a to e above to ascertain changes in performance. Between impacts, broken or cracked components are replaced, and optical devices realigned as necessary. If the vehicle is to be restored for service use, repairs (including repair welding of indentations in the armor) are performed at a site designated by the customer. Figure 5 shows typical effects on the outside of a tank.

Figure 5. Frontal Attack with AP Round to Evaluate Vulnerability of Periscope and Articulated Telescope in Tank, 90-mm Gun, M48.

5.4 Data Required.

a. Description of vehicle and components under test.

b. Caliber, weight, and model of projectile.

c. Striking velocities.

d. Exact location of each impact; also, thickness and obliquity of the armor, and direction of firing relative to the longitudinal centerline of the vehicle.

e. Type, characteristics, location, and time-versus-amplitude recordings of each strain, deflection, and acceleration gage.

f. Damage sustained by each component and identification of those that require replacement.

g. Performance data of equipment described in paragraph 4, both before and after firing.

5.5 Analytical Plan. Change in performance of each critical component is recorded. A destroyed component is considered a 100-percent loss.

The steps in the graphical presentation of accelerometer data are:

a. Acceleration (g) versus time (sec) curves. These show direct recordings of the raw data. Peak acceleration and duration of vibration are among the parameters depicted on the curves.

b. Fourier spectrum amplitude (g-sec) versus frequency (Hz) curves. This is the first step in ADP data reduction. The frequencies at which most of the vibrations occur are shown on the curves.

c. Equivalent static acceleration (g) versus frequency (Hz) curves. These are the final curves developed through ADP. They are useful to the designer for they show to what peak static acceleration a component must be designed if it is to be used at a certain location on a tank, given a component with a certain natural frequency.

A more detailed discussion on this matter is in appendix B.

6. High Energy Impacts on Sacrificial Armor.

NOTE: Sacrificial armor is a term applied to a piece of armor plate, cut, shaped, and wedged to be suitable for placing snugly against a section of an armored vehicle for the purpose of receiving the impact of an armor-piercing projectile, thereby saving the basic armor of the tank from damage. Theoretically, the projectile shock received by the sacrificial armor will be transmitted to the basic armor wall of the vehicle with approximately the same duration, intensity, and spectral pattern that would have occurred had the projectile struck the basic armor. In reality, however, the sacrificial armor provides a modest cushioning effect which can be compensated for by moderately increasing the striking velocity. Exploratory work on sacrificial armor is reported in reference 1 (app. A).

While sacrificial armor is used mostly in connection with tests of tank turrets, using 90-mm or 105-mm projectiles, it may also be used for lightly armored vehicles and employ projectiles of calibers ranging down to 20-mm.

6.1 Objective.

a. To determine the ability of the test vehicle and its components to withstand the impact of nonperforating impacts from kinetic energy projectiles, with the added provision that the basic armor of the vehicle must remain essentially undamaged from the impacts.

b. To obtain shock data suitable for use by engineers designing vehicle components.

6.2 Standards. Unless specifically designated otherwise, the turret must be able to withstand the shock and vibration from two impacts from armor-piercing projectiles (usually 90-mm or 105-mm) striking sacrificial armor at velocities that are close to the ballistic limit of the basic armor. Projectiles should impact within a 60° frontal arc (fig. 4), one on each side of the turret. Unless other criteria are established, the performance of components and subsystems will be expected not to be degraded by a factor of two as a result of a shock impact.

6.3 Method. All components of interest in the vehicle are checked out for integrity of mount and their performance ascertained. This may, as appropriate, include:

a. Boresight alignment (TOP/MTP 3-2-604).

b. Sight parallelogram error and backlash (TOP/MTP 3-2-701).

c. Range finder collimation (TOP/MTP 3-2-814).

d. Ballistic computer accuracies (TOP/MTP 3-2-700).

e. Traverse and elevation responses, handwheel torques, and brief samples of tracking and laying performance as described in TOP/MTP 3-2-603.

Appropriate instrumentation, described in paragraph 4, is installed inside of the turret and checked for response.

The preferred points of impact are two-thirds of the way up the turret on one side and one-third up the turret on the other, with projectiles impacting from 10° off the centerline to the right in one case and 10° to the left in the other. With sacrificial armor, however, such precise locations are rarely practical because the sacrificial armor, to be most effective, must fit snugly against the armor section that it is protecting. Thus, flat tank sections are most desirable, and these should be the areas selected for mounting of the sacrificial armor provided that the attack direction does not depart from the longitudinal centerline by more than 30°.

In order to absorb most of the backside bulge and spalling that would normally develop at ballistic limit velocities, the sacrificial armor is always thicker than the armor it is protecting. For tanks, the armor would be about 1 inch thicker than the armor it is protecting. The sacrificial armor may be machined or ground to improve the snugness of fit when the surface is curved. A less desirable method is the use of steel wedges, welded in place between the sacrificial armor and the tank armor.

For each intended point of impact the ballistic limit is estimated for the particular thickness and obliquity using ballistic information from a data bank. This becomes the velocity at which the projectile is fired at the sacrificial armor. (As indicated in the note above, the cushioning effect of the sacrificial armor reduces the net shock and vibration to the tank armor that would have occurred had the projectile been fired directly upon the tank armor. Thus, the basic armor is subjected to shock that is equal to the shock produced by a direct impact at perhaps 5% to 10% less velocity than the ballistic limit velocity.)

Projectile velocities are controlled by adjusting propellant weights. Following each impact, all interior components of the turret are examined for damage, and a check is made of all fire control components and other components listed in a table above to ascertain changes in performance. Between impacts, broken or cracked components are replaced, and optical devices are realigned as necessary. Upon completion of the firing, the sacrificial armor plates are removed. Any repairs that may be necessary to restore the vehicle to service use are performed at a site designated by the customer.

6.4 <u>Data Required</u>. (See para 5.4.)

6.5 <u>Analytical Plan</u>. (See para 5.5.)

7. <u>Graduated Energy Impacts with Proof Projectiles</u>.

NOTE: Proof projectiles are cylindrically shaped projectiles with a flat nose, made of soft mild steel or an aluminum alloy, and designed expressly for shock tests of armor. The projectiles, which for this purpose would be 57-mm, 75-mm, or 105-mm in diameter, will mushroom upon impact, rather than penetrating, thereby minimizing the damage to the target. The disadvantages of using proof projectiles, as compared to using sacrificial armor, are: (a) impacts by proof projectiles usually cause some deformation of the armor, though minor; (b) the mushrooming imparts shock in a different manner than an AP projectile and no correlations have ever been made of the two; and (c) proof projectiles cannot be fired to impact at velocities much greater than 1500 fps because extreme projectile breakup will occur. The advantage of using proof projectiles is that costs and time are less than with sacrificial armor.

7.1 Objective. The objective of this test is to determine the impact kinetic energy at which tank components, particularly portions of the fire control system, will fail. This test is designed to aid the designer to establish the shock and vibration limits of his design without risking major damage from excessively high energy impacts. The test types involved are usually the engineer design test or product improvement tests, not the DT I, II, or III.

7.2 Standards. The energy of impacts will be in accordance with the desires of the customer. The conversion from an armor-piercing projectile of a certain weight and velocity to a proof projectile of a different weight and velocity will be made strictly in accordance with equivalent kinetic energies.

7.3 Method. The preferred areas to be fired upon are those that are as close to 0° obliquity as possible. Unless other procedures are specified in the directive, the following will be used: The first proof projectile is fired to impact at a velocity that represents a kinetic energy (KE) equal to one-half of that represented by the ballistic limit of an armor-piercing projectile, or 1/2 KE (AP). Each succeeding proof projectile (two or three more) is fired at a progressively higher velocity, until the KE reaches a level of 0.9 KE (AP). Impacts can be placed as required on either side of the turret. After each impact the turret components, such as range finders, periscopes, telescopes, ballistic computers, turret control systems, loading devices, etc., are examined for damage. Triaxial accelerometers are mounted at important locations within the turret. As the test progresses, components of interest that become damaged should be replaced to preclude progressive type failures. Firing is halted if excessive damage occurs.

7.4 Data Required. After each round is fired data are recorded as follows:

a. Caliber, weight, and model of the projectile.

b. Striking velocity and KE of each impact.

c. Exact point of impact and direction of firing.

d. Acceleration-versus-time recordings.

e. Locations of accelerometers.

f. Visible damage sustained by each component.

g. Performance data collected before and after firing, as described in the applicable sections of paragraph 6.3.

h. Replaced components.

i. Temperature.

7.5 <u>Analytical Plan</u>. (See para 5.5.)

8. Blast and Fragmentation Effects.

NOTE: This test, which involves the static detonation of HE projectiles in close proximity to an armored vehicle, is more often used to ascertain the probability of perforations and damage from fragments than to determine blast or shock effects, since an impacting KE projectile would be far more damaging to internal components and since the probability of a projectile's detonating in the air very close to an armored vehicle is rather remote. External damage to protruding optical devices is, however, a possibility. With lightly armored vehicles this test is often more appropriate than those of paragraphs 5, 6, or 7.

8.1 <u>Objective</u>. Unless the directive states otherwise, the objective is to determine the vulnerability of interior and exterior components, such as fire control components, to blast and fragmentation from HE shell by conducting static detonation tests.

8.2 <u>Standards</u>. The caliber and mode of HE projectile and its distance and orientation from the vehicle may be specified in the requirements document or test directive, as will the acceptable level of damage. If not given in these documents, the location of the shell will be in accordance with the AMSAA fragment penetration model using a scenario developed by the user, or at locations where results can be compared to results from prior tests of a similar nature.

8.3 <u>Method</u>. Each projectile is suspended and statically detonated at locations determined as explained in 8.2 above. TOP 2-2-722 covers this method in detail.

8.4 <u>Data Required</u>. Type, location, and orientation of each projectile are recorded. All damage is recorded.

8.5 <u>Analytical Plan</u>. Where required, the probability of certain types of damage occurring from artillery barrages is determined based upon the damage observed and the AMSAA model. (See also TOP 2-2-722.)

APPENDIX A
REFERENCES

1. Coryell, James W., "Special Test of Sacrificial Armor for Tank Shock Tests," Aberdeen Proving Ground, Md., Report APG-MT-3940, TECOM Project 9-CO-001-000-043, October 1971.

2. Walton, W. Scott, "Shock Data Reduction for Multiple Degrees of Freedom Systems," Aberdeen Proving Ground, Md. TECOM Project 9-CO-001-000-097 (expected date of issue - December 1974).

APPENDIX B
SHOCK DATA ANALYSIS

1. Data. Raw data are usually in the form of an acceleration-versus-time record on magnetic tape. Since the accelerometer itself is a single-degree-of-freedom system, vibrations at frequencies above approximately 50% of the accelerometer's natural frequency will be magnified and hence erroneous. Such data can normally be removed with a low pass filter with a cutoff frequency set at 0.5 times the accelerometer's natural frequency. Although this filtering necessarily eliminates some data, the data will be of limited interest if the natural frequency of the accelerometer is ~ 30 kHz or higher. Acceleration at frequencies above the acoustic level (~ 15 kHz) rarely account for significant damage. To sustain sufficient deflection for damage of any item with finite mass, astronomical acceleration values would be required at these frequencies.

2. Fourier Spectrum. The amplitude portion of the Fourier spectrum of a given time history can readily be obtained with a Real Time Spectrum Analyzer. The resulting plot shows energy content versus frequency. Since projectile impact is normally much shorter in time than one period of vibration, it can be considered an impulse; that is, the impact imparts an instantaneous velocity and little or no displacement to the system, which then oscillates at its natural frequency. The natural frequency of the system is readily apparent in the Fourier spectrum plot. Since most of the vibration occurs at the natural frequency, a large spike will appear at this frequency as shown in figure 6.

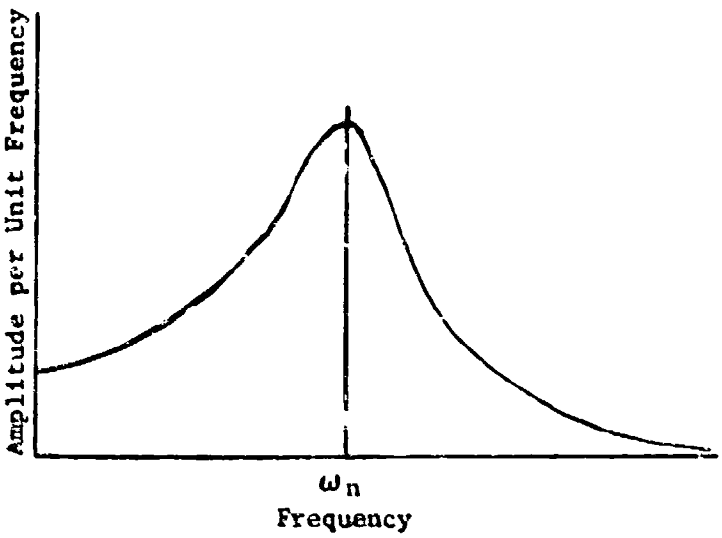


Figure 6. Fourier Amplitude vs Frequency for Free Vibration of a Single-Degree-of-Freedom System.

3. Shock Spectrum. The shock spectrum is the most useful tool in evaluating shock records. This spectrum is basically a calculation of how the given shock will affect various single-degree-of-freedom systems. The plot is presented as static equivalent acceleration versus natural frequency; that is, given a spring-mass system of natural frequency X, its response to the given shock is equivalent to a steady acceleration of value Y (fig. 7).

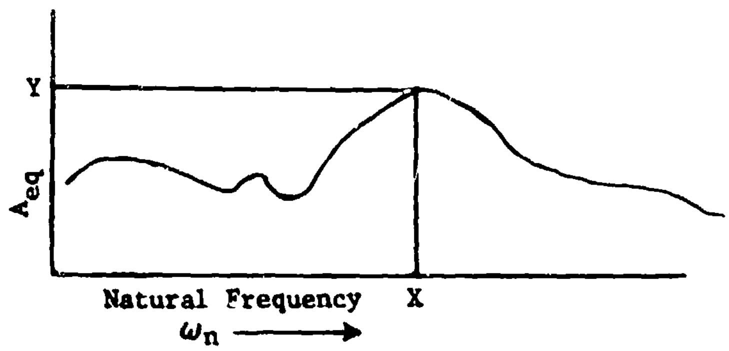


Figure 7. Static Equivalent Acceleration vs Natural Frequency, Single-Degree-of-Freedom System.

This plot is obtained by calculating the displacement versus time response of a single-degree-of-freedom system with a particular natural frequency to the given shock impulse. The maximum displacement δ max is found and the equivalent static acceleration is found as follows:

$$A_{eq} = \frac{\delta max \ (\omega n)^2}{g}$$

This formula is only applicable to systems with little or no damping ($\xi \leq 0.1$), but low damping is characteristic of metal structures.

If a component or subsystem can be modeled as a single-degree-of-freedom system and its natural frequency calculated, the shock spectrum analysis will immediately reveal the static equivalent acceleration. The loading of the component can then be found and failures predicted.

Since the vehicle transfer function does not normally exhibit amplitude-related nonlinearities and the projectile impact is essentially an impulse, the profile of the shock spectrum should not change with the intensity of impact (fig. 8). This characteristic allows the prediction of the shock spectrum for a high energy impact to be made from a low energy impact. As impact energy is increased, the basic trend of the shock spectrum becomes visible, and it can be predicted before firing that the magnitude of loading will be sustained.

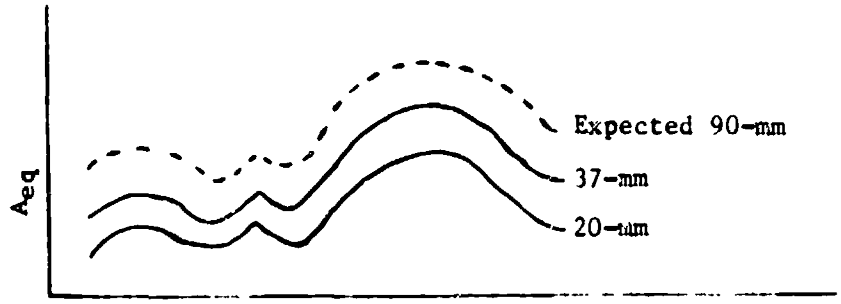


Figure 8. Shock Spectra at Different Impact Energies Showing Constant Profile.

Usually when the mass of a component is small compared to the mass of the base to which it attaches, the response of the base to an impulse will be the same whether the component is mounted or not. If it is important to avoid damaging a component, an accelerometer alone can be fixed to the base during firing and a shock response spectrum obtained. Then the component mount can be designed to change the natural frequency of the mounted component to the frequency with least equivalent static acceleration before subjecting the component to live firing.

A computer program is available to compute single-degree-of-freedom shock spectra. Solid state electronic machines are available commercially to provide single-degree-of-freedom shock spectra instantaneously. A computer program to calculate two-degree-of-freedom shock response spectra will be available soon.

4. <u>Cross-Correlation.</u> The cross-correlation function is a quantitative measure of the relationship between a given signal and some other signal a time γ later. If the value of $\psi xy(\gamma)$ is unity, then the signal at x is exactly the same as the signal at y except that it is delayed by time γ. Figure 9 is a classic example of a correlation function.

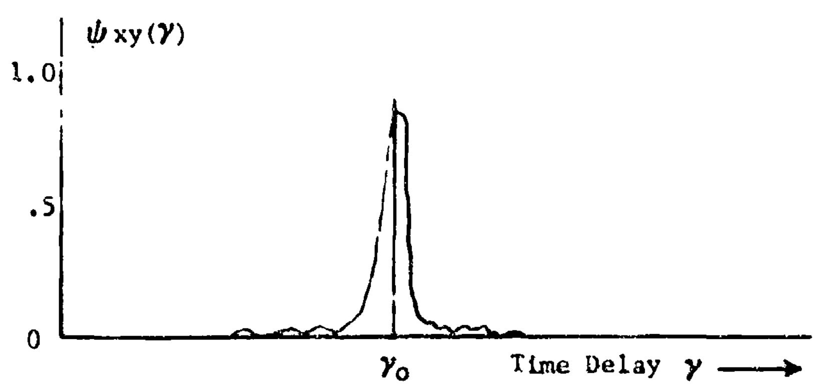


Figure 9. Cross-Correlation of Hypothetical Frequency Independent Random Process.

This relationship is typical of a system with some sort of frequency independent time delay. For small values of γ little or no relationship exists between the signal at x and the signal at y. Then at a certain time γ_0 later the relationship reaches a maximum, after which the relationship decreases again to zero.

If several transducers are placed in a turret as shown in figure 10, cross-correlation between the signal can be made.

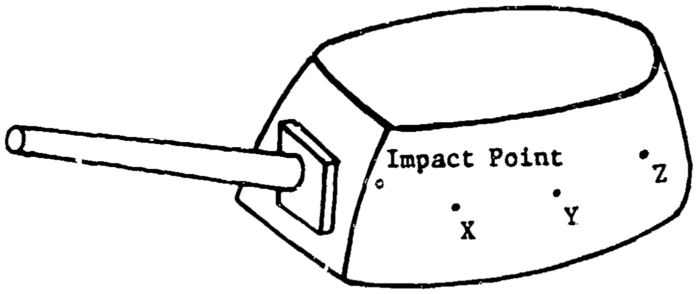


Figure 10. Transducer Locations in a Turret.

From the correlation the time delay γ_0 between, say, point X and point Y is determined. Knowing this time and the speed of sound in the turret, it is possible to calculate the distance the shock traveled and perhaps define the geometric path of the shock. If changes in hull construction are made to absorb vibration or otherwise reduce the transmission of shock, the amplitude of the cross-correlation function (which is proportional to received signal strength) should decrease.

Solid state electronic correlators are available for this work. The acceleration records must of course be time synchronized in some manner, such as recording all records on a multichannel tape recorder.

5. Actual Results. Examination of actual data reveals more complex situations than encountered in theoretical analysis of classic conditions. Two shot records are examined here to exemplify real life conditions. The first record, shown in figure 11A, consists of a single spike, reaching about 260 g. In the low frequency domain, this sort of excitation can be considered an impulse. The Fourier spectrum of an impulse is a horizontal line, which is approximately the shape of figure 11B below 1000 Hz. The response spectrum for an impulse is a straight line with a positive slope as shown in figure 12A, which, when plotted in semilog form, will be concave upward as shown in figure 12B. The actual response spectrum shown in figure 11C is similarly concave upward in the region below 1000 Hz.

For higher frequencies it must be recognized that the impulse has finite width and should be considered a rectangular pulse of width ϵ. The Fourier spectrum of a rectangular pulse is of the form

$$\left| \frac{\sin x}{x} \right|$$

A

B

C

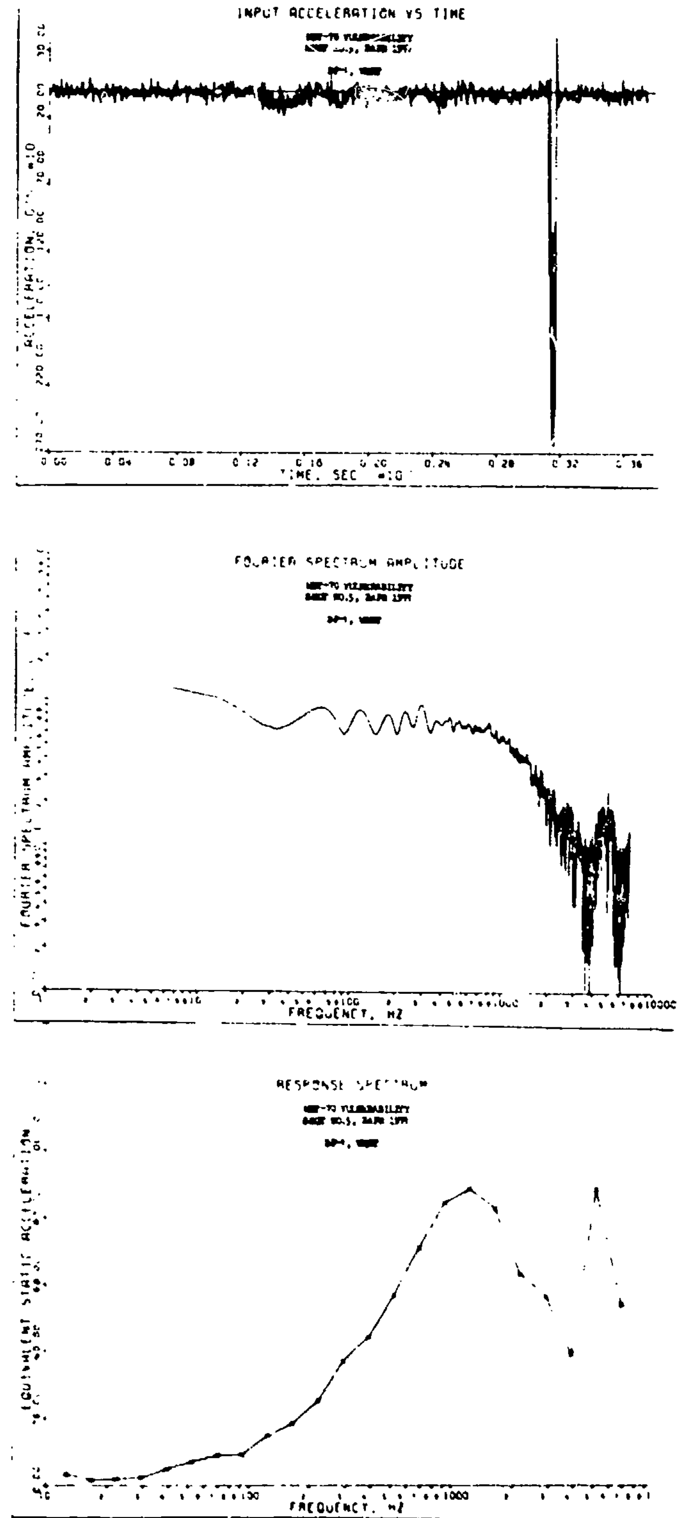
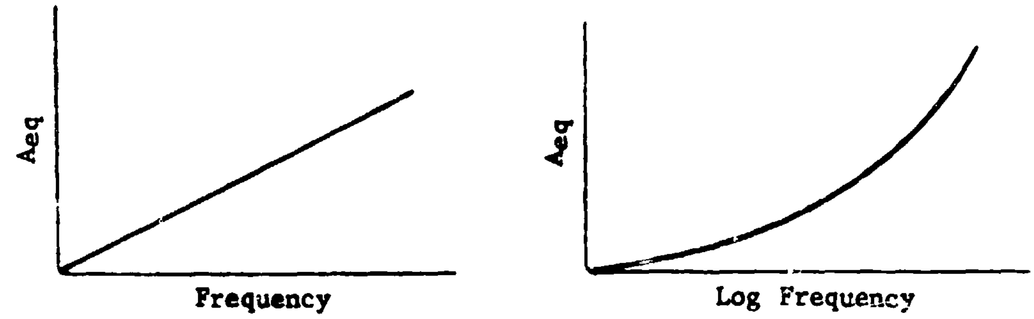


Figure 11. Typical Waveforms Resulting From Impacting Projectile (Location 1).



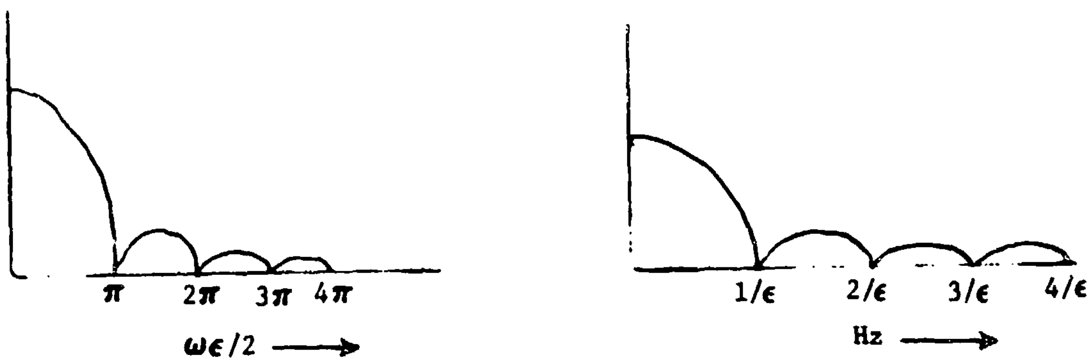
A. Linear Plot B. Semilog Plot

Figure 12. Response Spectrum to Impulse.

where x is $\omega\epsilon/2$ as shown in figure 13A. If the abscissa is plotted in Hertz, the null points will occur at $1/\epsilon$, $2/\epsilon$, etc. (fig. 13B). Figure 11B shows the first null point occurring at 3.5×10^3 Hz which corresponds to

$$\epsilon = \frac{1}{3.5 \times 10^3} = 0.4 \times 10^{-3} \text{ sec.,}$$

which is about the width of the spike shown in figure 11A.



A. B.

Figure 13. Fourier Spectrum of Rectangular Impulse.

In figure 11 the response spectrum dips at frequencies corresponding to the null points of the Fourier spectrum (i.e., 3.5 kHz, 7 kHz, etc.). Although the acceleration spike reached 260 g, the equivalent static acceleration of a single degree of freedom is below 100 g. In addition, if the single degree of freedom has a low natural frequency (below 100 Hz), the equivalent static acceleration will be below 20 g. Figure 14 shows a complex input reaching a maximum of 150 g and containing more low frequency content than the impulse of figure 11. The Fourier

spectrum shows a small spike at ~60 Hz and null points at ~120 and ~520 Hz. (Note the spike and dips at these same frequencies in the response spectrum, fig. 14C.) The most useful information comes from figure 14C. This plot shows that a single-degree-of-freedom system with a natural frequency of 60 Hz would receive considerably more loading than systems of other natural frequencies. Although the input acceleration in figure 14A reached 150 g, the equivalent static acceleration of a single degree of freedom does not exceed 60 g and is less than 30 g for systems with natural frequencies other than 60 Hz.

Input accelerations as shown in figure 14 suggest that components should have high frequency mountings such as metal-to-metal support. Accelerations as found in figure 6 suggest that components should have low frequency mountings such as soft shock mounts.

A

B

C

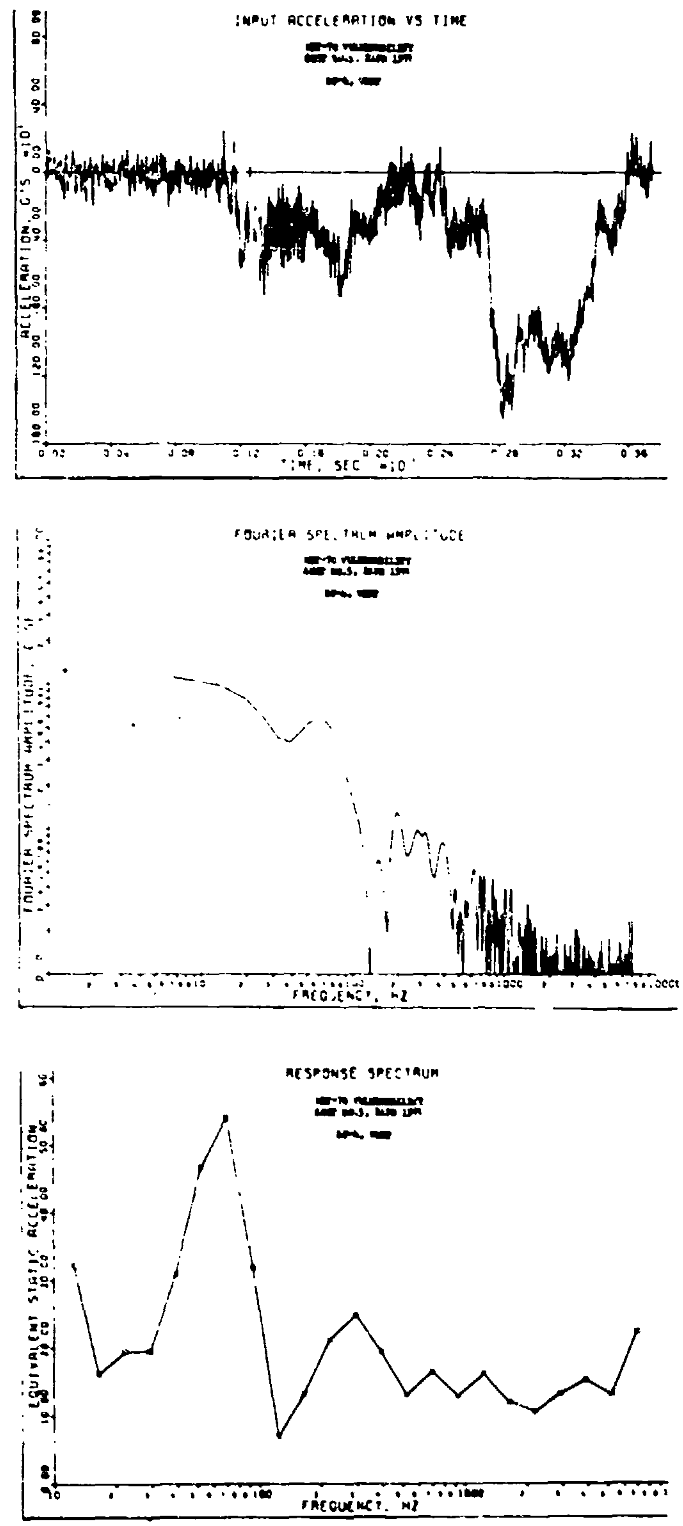


Figure 14. Typical Waveforms Resulting From Impacting Projectile (Location 4).